BRL

REPORT NO. 401

THE EFFECT OF PREVIOUS HIGH VELOCITY ROUNDS ON ZONE I MUZZLE VELOCITIES AND COPPER PRESSURES IN 105MM AND 155MM HOWITZERS

by

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September 1943

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Ballistic Research
Laboratory Report No. 401

Sarmousakis/hlh
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Abstract

It has been found that there is a monotonically increasing trend in Zone I velocities following high velocity rounds in 105mm Howitzer, M2E1, No. 3, firing Proof Slug, E2, and Shell, H.E., M1, and in 105mm Howitzer, M2A1, No. 79, firing Proof Slug, E2. Correspondingly, there appears to be a possible decreasing trend in copper pressures in both weapons firing both projectiles. This phenomenon has also been noted in the results of firings of 155mm Howitzer, T1, No. 2, firing Proof Slug, T11. The Zone I velocities in 105mm Howitzer, No. 79, firing Shell, H.E., M1, increased to a maximum, then decreased. The explanation of these trends as due to coppering of the bore and the use of decoppering agents to eliminate it have been discussed.

INTRODUCTION

It is the purpose of this report to describe the work done on the effect of previous high velocity rounds on Zone I muzzle velocities and maximum powder pressures in the 105mm and 155 mm Howitzers.

INVESTIGATION OF EFFECT OF PREVIOUS ROUNDS

By an application of a significance test based on the statistic,[1,2] δ^2/s^2, it has been shown[3] that the dispersions in muzzle velocity in a set of uniformity series of Zone I firings in the 105mm howitzer were, for the greater part, due to trends. The use of a relatively quick powder in the base section of the powder charge was shown not to diminish the dispersion greatly. The hypothesis was proposed that these trends had some connection with the condition of coppering or other deposit in the bore.

Later, it was reported[4] that, when Zone VII rounds plus two excess-pressure rounds in 105mm Howitzer, M2E1, No. 3, were followed by Zone I rounds, the velocities in the Zone I rounds tended to increase monotonically from the first, to the second, and so on.

The statistical analysis of this trend of Zone I velocities and of the corresponding maximum pressures, first noted by H. Mark, was carried through by Miss Mark and Miss B. I. Hart with later finishing touches by the writer under the direction of R. H. Kent. The effect of previous high velocity rounds on Zone I velocities and pressures was similarly studied for firings of 105mm Howitzer, M2A1, No. 79 and 155mm Howitzer, T1, No. 2.

The data employed were taken from powder acceptance test firing records. In each record are given muzzle velocities and copper pressures for 7 rounds fired in Zone I, following at least 7 rounds fired in a high zone of the howitzer (Zone VII for 105mm, Zone V for 155mm) usually followed by 2 rounds at excess pressure. The numbers of the firing records, of Zone I rounds fired, and of powder lots tested in each cannon with each type of projectile, are listed in Appendix A, Tables VII and VIII for H.E. Shell M1 and Proof Slug, E2, respectively, in 105mm Howitzer M2E1, No. 3; Table IX and X for H.E. Shell M1 and Proof Slug E2, respectively, in 105mm Howitzer, M2A1, No. 79, and Table XI for Proof Slug, T11, in 155mm Howitzer, T1, No. 2.

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1 J. von Neumann, Ann. Math. Statistics, 12, 367 (1941).
2 B. I. Hart, ibid., 13, 207, 445 (1942).
3 R. H. Kent, "Experiments with Dual Granulation Charges in the 105mm Howitzer, M2", BRL Report No. 294, 25 July 1942.
4 2nd Wrapper Ind. by R. H. Kent to OO 063.2/68(r), 063/3(r)-GNRQT, SPRMD 063.2; APG 353.42/1056.

The materiel used in the acceptance tests is listed in the following outline which gives the weapon, type of projectile, and propellent components for each type of projectile.

I. Weapons
  A. 105mm Howitzer, M2E1, No. 3
    1. Projectiles
      a Shell, H.E., M1, 33 lb., Dwg. 75-4-75, hexagonal plug in nose. B.S. Lot 2956-1 for 7 uniformity groups; B.S. Lot 3311-8 for 1 uniformity group; lot number not given in firing record for 17 uniformity groups.
      b Slug, Proof, E2, 33 lb., Dwg. 75E-4-65C for 15 uniformity groups.
        (1) Propellent components for both projectiles
          (a) Cartridge Case, M14, Dwg. 71-2-101
          (b) Bag, Cotton, Dwg. 71-9-100
          (c) Primer, 100 Gr. Perc., M1B1A1, P.A. Lot 2916-70
          (d) Propellent powder lot numbers given in Appendix A, Table VII for shells, Table VIII for slugs.
  B. 105mm Howitzer, M2A1, No. 79.
    1. Projectiles
      a Shell, H.E., M1, 33 lb., circular plug in nose, Dwg. 75-4-75. N.T. Lot 443-10 (filled with sand and steel punchings) for 27 uniformity groups.
        (1) Propellent components
          (a) Cartridge Case, M14, Dwg. 71-2-101, various lots
          (b) Cotton bags, Dwg. 71-9-100 for 6 uniformity groups; Grade B, Dwg. 71-9-100 for 11 uniformity groups; Grade C, Dwg. 71-9-100 for 10 uniformity groups.
          (c) Primer, 100 gr., Perc., M1B1A1, P.A. Lot 2916-68 for 11 uniformity groups; P.A. Lot 5296-12 for 16 uniformity groups
          (d) Propellent powder lot numbers given in Appendix A, Table IX.
      b Slug, Proof, E2, U.S. Pipe and Foundry Co. Lot 1-22086-1 for 11 uniformity series.
        (1) Propellent components
          (a) Cartridge Case, M14, various lots.
          (b) Bag, Cotton, Grade C, Dwg. 71-9-100.
          (c) Primer, 100 Gr., Perc., M1B1A1, P.A. Lot 5296-12 for 11 uniformity series.
          (d) Propellent powder lot numbers given in Appendix A, Table X.
  C. 155mm Howitzer, T1, No. 2.
    1. Projectile
      a Slug, Proof, T11,95 lb., G.A. Sketch 1990, Le Tourneau Co.

(1) Propellent components
   (a) Black powder, Grade A1, 3 oz. at base of base section.
   (b) Bag, Cotton, Grade B, M3 Charge (Green) Dwg. 71-9-177.
   (c) Primer, 21 Gr., Perc., Mk. IIA1, P.A. Lot 2741-4 for 47 uniformity groups; P.A. Lot 5319-13 for 41 uniformity groups.
   (d) Propellent powder lot number given in Appendix A, Table XI.

The procedure used in the analysis of the data follows:

In any 7-round uniformity group at Zone I let the successive velocities be $v_1, v_2, \ldots, v_7$. The six quantities, $v_{n+1} - v_1$, $(n = 1, 2, \ldots, 6)$ were computed. The mean, $\overline{v_{n+1} - v_1}$ of each difference, $v_{n+1} - v_1$, over the Zone I uniformity series in all the firing records for one type of projectile in each weapon, was computed, together with the probable error of the mean. A suitable curve to represent the relation of $\overline{v_{n+1} - v_1}$ to n was then fitted to the data by the method of least squares.

The same procedure was then carried out for the copper pressures except that curves were not fitted to the results.

The results are tabulated in Tables I to V.

TABLE I

Weapon, 105mm Howitzer, M2E1, No. 3
Projectile, Shell, H.E., M1
No. of Uniformity Groups, 25

n	$\overline{v_{n+1}-v_1}$ in f/s	Probable Error in $\overline{v_{n+1}-v_1}$ in f/s	$\overline{P_{n+1}-P_1}$ in psi	Probable Error in $\overline{P_{n+1}-P_1}$ in psi
1	10.50	1.17	-148	41
2	17.63	1.11	-168	51
3	21.92	1.28	-264	59
4	27.00	1.27	- 84	56
5	28.17	1.29	-152	54
6	29.63	1.15	-188	44

Equation[5] fitted by method of least squares:

$$\overline{v_{n+1} - v_1} = 33.3(1 - 10^{-0.163n})$$

5 Form of equation suggested by Major T. E. Sterne.

TABLE II

Weapon, 105mm Howitzer, M2E1, No. 3
Projectile, Proof Slug, E2
No. of Uniformity Groups, 15

n	$\overline{v_{n+1}-v_1}$ in f/s	Probable Error in $\overline{v_{n+1}-v_1}$ in f/s	$\overline{P_{n+1}-P_1}$ in psi	Probable Error in $\overline{P_{n+1}-P_1}$ in psi
1	10.36	1.16	-273	56
2	20.33	1.31	-233	47
3	25.40	1.22	-153	49
4	27.80	1.43	-253	55
5	27.49	1.57	-380	64
6	28.27	1.40	-207	62

Equation[5] fitted by method of least squares:

$$\overline{v_{n+1} - v_1} = 30.1(1 - 10^{-0.231n})$$

TABLE III

Weapon, 105mm Howitzer, M2A1, No. 79
Projectile, Shell, H.E., M1
No. of Uniformity Groups, 27

n	$\overline{v_{n+1}-v_1}$ in f/s	Probable Error in $\overline{v_{n+1}-v_1}$ in f/s	$\overline{P_{n+1}-P_1}$ in psi	Probable Error in $\overline{P_{n+1}-P_1}$ in psi
1	5.22	0.94	-165	31
2	7.26	1.21	-246	38
3	9.59	1.17	-165	43
4	7.81	1.14	-288	38
5	6.04	1.03	-319	34
6	3.96	0.98	-373	38

Equation fitted by method of least squares:

$$\overline{v_{n+1} - v_1} = 1.64 + 4.29n - 0.662n^2$$

Table IV

Weapon, 105mm Howitzer, M2A1, No. 79
Projectile, Proof Slug, E2
No. of Uniformity Groups, 11

n	$\overline{v_{n+1}-v_1}$ in f/s	Probable Error in $\overline{v_{n+1}-v_1}$ in f/s	$\overline{P_{n+1}-P_1}$ in psi	Probable Error in $\overline{P_{n+1}-P_1}$ in psi
1	7.20	1.29	-200	64
2	12.09	1.52	-58	71
3	9.09	0.86	-225	84
4	12.09	1.55	-125	66
5	12.82	1.01	- 92	67
6	12.82	1.07	-233	63

Equation[5] fitted by method of least squares:

$$\overline{v_{n+1} - v_1} = 12.4(1 - 10^{-0.400n})$$

TABLE V

Weapon, 155mm Howitzer, T1, No. 2
Projectile, Proof Slug, T11
No. of Uniformity Groups, 88

n	$\overline{v_{n+1}-v_1}$ in f/s	Probable Error in $\overline{v_{n+1}-v_1}$ in f/s	$\overline{P_{n+1}-P_1}$ in psi	Probable Error in $\overline{P_{n+1}-P_1}$ in psi
1	3.31	0.36	-142	22
2	4.23	0.41	-190	23
3	4.88	0.44	-289	25
4	6.01	0.48	-307	26
5	7.02	0.50	-280	25
6	7.20	0.49	-380	26

Equation[5] fitted by method of least squares:

$$\overline{v_{n+1} - v_1} = 7.8(1 - 10^{-0.176n})$$

The results in Tables I to V are represented graphically in Figs. I to V respectively.

From the tables and graphs, it is seen that the monotonic rise in muzzle velocity for the Zone I rounds is found for all weapons and projectiles except for shell fired in the 155mm Howitzer, M2A1, No. 79. The increase is largest from the first to the second round and decreases from round to round so that the muzzle velocity appears to rise to an asymptotic value given by the constant a in the equation,

$$\overline{v_{n+1} - v_1} = a\ (1 - 10^{-bn})$$

to which the points $(\overline{v_{n+1}-v_1}, n)$ have been fitted.

For shell fired in 105mm Howitzer, M2A1, No. 79, the values of $v_{n+1}-v_1$ rise from n = 1 to a maximum of n = 3 and decrease again. The reason for this difference in previous round effects is not understood.

Inspection of Figs. I to V indicates that, for all weapons and projectiles considered, the copper pressure for the first round at Zone I is greater than that for all succeeding rounds in the same zone. Fig. III for 105mm Howitzer, M2A1, No. 79, firing Shell, H.E., M1, and Fig. V for 155mm Howitzer, T1, No. 2, show definite monotonic downward trends in copper pressures. Figure III thus exhibits an anomaly in the trends shown by the velocities and pressures for 105mm Howitzer No. 79 firing H.E. Shell, M1, for it is reasonable to associate a monotonic trend in pressures with a monotonic trend in velocities.

At the request of the Ballistic Research Laboratory, firings have been carried out which indicate the following results:

1. The phenomenon of an increasing trend in Zone I velocities following 7 rounds at Zone VII and 2 excess pressure rounds also occurs[6] in 105mm Howitzers, No. 146, 1567, 1568, 1572, 1573 and 3307.

2. This phenomenon is apparently not eliminated[7] when relatively quick powders are employed in the Zone I firings.

3. Sponging the bore of a 105mm howitzer with water immediately after the high velocity rounds seems not to eliminate the rising trend of velocities in the immediately following Zone I rounds.[8]

6 APG Firing Record No. M12188.
7 APG Firing Records No. M13090, M13126, M14150, and M14446.
8 APG Firing Records No. M133127 and M14446.

4. A rising trend in velocities following high velocity rounds can occur for firings in Zone II following Zone VII rounds, while there is no apparent effect of the rounds in Zone II upon the velocities in immediately following Zone I rounds.[9]

At the request of Lt. Col. J. W. Cave, firings have been carried out which showed that addition of 1/3 ounce of tin foil (60% tin, 40% lead) to the Zone VII, excess pressure, and Zone I charges seems effectively to eliminate the rise in velocity in Zone I rounds succeeding Zone VII and excess pressure rounds.[10]

It is stated in APG F.R. No. 16607 that, when tin foil is used in the firings, visual inspection of the muzzle indicates that the coppering of the tube was removed after the second round and successive rounds left no noticeable copper deposit.

A tabulation to illustrate the effect of tin foil on the effect of previous high velocity rounds on Zone I velocities is given in Table VI.

TABLE VI

EFFECT OF TIN FOIL ON ZONE I VELOCITIES
FOLLOWING HIGH VELOCITY ROUNDS

	105mm Howitzer No. 1573				105mm Howitzer No. 3			
	without* tin foil		with** tin foil		without*** tin foil		with*** tin foil	
Charge Zone	Rd. No.	Muzzle Velocity f/s	Rd. No.	Muzzle Velocity f/s	Rd. No.	Muzzle Velocity f/s	Rd. No.	Muzzle Velocity f/s
VII	13	1579	152	1585	5873	1561	5889	1598
"	14	1579	153	1585	5874	1564	5890	1566
"	15	1576	154	1581	5875	1562	5891	1572
"	16	1578	155	1580	5876	1564	5892	1572
"	17	1577	156	1583	5877	1561	5893	1563
"	18	1577	157	1579	5878	1560	5894	1563
"	19	1579	158	1580	5879	1558	5895	1563
Ex.Pres	20	1629	159	1636	5880	1606	5896	1611
"	21	1631	160	1637	5881	1605	5897	1616
I	22	673	161	698	5882	639	5898	658
"	23	682	162	698	5883	648	5899	653
"	24	689	163	695	5884	646	5900	659
"	25	690	164	699	5885	657	5901	655
"	26	688	165	693	5886	665	5902	658
"	27	695	166	700	5887	662	5903	650
"	28	700	167	700	5888	660	5904	651

*F. R. No. M12188. **F.R. No. M16607. ***F. R. No. M17717

9.APG Firing Record No. 12840.
10.APG Firing Records M16607, M17717, M19303.

It will be noted that the velocities in the Zone I rounds with tin foil, on the average, are quite close to the maximum velocities in the Zone I rounds without tin foil.

This observation is in agreement with the view[11] that rounds fired at Zone I tend to decopper the bore, while rounds fired at Zone VII and excess pressure tend to copper the bore. Without tin foil, the copper deposit due to the Zone VII and excess pressure rounds in a howitzer is removed progressively as Zone I rounds are fired. The velocity increases at a rate which is a function of the amount of deposit in the bore so that a maximum value of the velocity is approached asymptotically. The tin foil added to the charge, however, combines with the copper deposit to produce a soft alloy which immediately cuts down the resistance of the copper deposit to the motion of the shell so that the Zone I velocity reaches a value close to the asymptotic value without tin foil immediately.

From the results of one set of firings[12] it would appear that lead foil has no effect similar to that of tin foil on Zone I velocities in the 105mm howitzer after high velocity rounds. Aluminum foil has been shown[13] not to have any decoppering effect since it is oxidized during the burning of the powder.

RECOMMENDATIONS

1. Since the trends in Zone I velocities in the 105mm and 155mm howitzers seem to be eliminated by adding tin foil to the propelling charge, it is recommended that there be considered the addition of tin to the propelling charges of these guns, and all others for which such trends may be found.

2. It is recommended that the effect of previous high velocity rounds in producing trends of low zone velocities and pressures be investigated in other guns beside those considered in this report.

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11 Third Report on Ordnance Program No. 5412.
12 APG Firing Record No. M19303.
13 ABG Firing Record No. M22549.

APPENDIX A.

Tables of Firing Record Numbers, Zone I Round Numbers, and Powder Lot Numbers Involved in the Report.

Table VII

Weapon, 105mm Howitzer, M2B1, No. 3.
Projectile, Shell, H.E., M1.

APG F.R. No.	Zone I Round No.	IOW Powder Lot No.
M747	2522-2528	X6203
M478	2540-2546	X6204
M753	2577-2583	X5688
M755	2595-2601	X6207
M770	2613-2619	X5689
M769	2631-2637	X6205
M771	2649-2655	X5690
M772	2667-2673	X5691
M904	2706-2712	X5692
M906	2722-2728	X5694
M908	2742-2748	X5696
M909	2760-2766	X5697
M910	2778-2784	X5698
M907	2796-2802	X5695
M921	2833-2839	X5700
M922	2851-2857	X5701
M926	2869-2875	X5704
M925	2889-2895	X5703
M927	2907-2913	X5702
M928	2925-2931	X5705
M929	2943-2949	X5706
M930	2961-2967	X5707
M966	3024-3030	X5709
M967	3042-3048	X5711
M968	3060-3066	X5712

Table VIII

Weapon, 105mm Howitzer, M2E1, No. 3
Projectile, Proof Slug, E2.

APG F.R. No.	Zone I Round No.	IOW Powder Lot No.
M250	2100-2106	X6180
M251	2118-2124	X6181
M273	2155-2161	X6183
M284	2173-2179	X6184
M294	2191-2197	X6185
M295	2209-2215	X6186
M366	2246-2252	X6188
M661	2321-2327	X6192
M664	2339-2345	X6193
M680	2376-2382	X6195
M681	2394-2400	X6196
M683	2412-2418	X6197
M684	2430-2436	X6198
M704	2467-2473	X6200
M705	2485-2491	X6202

Table IX

Weapon, 105mm Howitzer, M2A1, No. 79
Projectile, Shell, H.E., M1

APG F.R. No.	Zone I Round No.	Powder Lot No.
M2346	92- 98	ROW X5001
M6393	170- 176	DP 4619
M6558	217- 223	DP 4620
M6850	262- 268	DP 4621
M8451	650- 656	AOW 8877
M8452	668- 674	AOW 8878
M8504	695- 701	AOW 8879
M8505	713- 719	AOW 8880
M8506	731- 737	AOW 8881
M6905	289- 295	PA 131
M6905	311- 317	PA 132
M6904	329- 335	PA 133
M7428	374- 380	DP 4622
M7717	401- 407	AOW 8872
M7716	421- 427	AOW 8873

Table IX (Continued)

APG F.R. No.	Zone I Round No.	Powder Lot No.
M7898	457- 463	DP 4626
M8394	587- 593	AOW 8874
M8426	605- 611	AOW 8875
M9399	890- 896	PA 3994
M9435	908- 914	AOW 8883
M9436	926- 932	AOW 8884
M9437	944- 950	AOW 8885
M8507	749- 755	AOW 8882
M8625	776- 782	DP 4624
M9118	812- 818	DP 4625
M9188	843- 849	PA 3992
M9189	863- 869	PA 3993

Table X

Weapon, 105mm Howitzer, M2A1, No. 79.
Projectile, Proof Slug, E2.

APG F.R. No.	Zone I Round No.	Powder Lot No.
M9985	1043-1049	PA 3997
M9501	971- 977	PA 3995
M9812	998-1004	DP 4626
M10028	1072-1078	DP 4627
M10090	1099-1105	PA 3998
M10302	1126-1132	PA 4453
M10398	1153-1159	PA 4454
M10501	1180-1186	DP 4628
M10537	1207-1213	PA 4456
M10753	1234-1240	DP 4629
M10890	1261-1267	PA 4457

Table XI

Weapon, 155mm Howitzer, T1, No. 2
Projectile, Proof Slug, T11

APG F.R. No.	Zone I Round No.	ROW Powder Lot No.
M8985	1023-1029	4970
M8986	1041-1047	4971
M8990	1059-1065	4975
M8989	1077-1083	4977
M8998	1095-1101	4972
M8999	1113-1119	4976
M9019	1131-1137	4973
M9020	1149-1155	4974
M9617	1709-1715	7370
M9618	1727-1733	7371
M9619	1745-1751	7372
M9620	1763-1768	7374
M9621	1781-1787	7375
M9646	1799-1805	7376
M9647	1817-1823	7377
M9648	1833-1839	7378
M9669	1883-1889	7380
M9670	1901-1907	7381
M9672	1937-1943	7373
M9673	1955-1961	7383
M9829	2081-2087	7384
M9831	2117-2123	7386
M9834	2135-2141	7389
M9832	2153-2159	7387
M9833	2171-2177	7388
M9836	2189-2195	7391
M9837	2207-2213	7392
M9838	2225-2231	7393
M9839	2243-2249	7394
M9840	2261-2267	7395
M9841	2279-2285	7396
M9835	2912-2918	7390
M10130	2930-2936	7397
M10163	2948-2954	7398
M10173	3016-3022	7400
M10168	3034-3040	7401
M10169	3052-3058	7617
M10170	3070-3076	7618
M10175	3088-3094	7619

Table XI (Continued)

APG F.R. No.	Zone I Round No.	ROW Powder Lot No.
M10176	3106-3112	7620
M10368	3301-3307	7621
M10392	3319-3325	7622
M10393	3337-3343	7624
M10361	3355-3361	7625
M10362	3373-3379	7626
M10363	3391-3397	7627
M10394	3409-3415	7628
M10395	3427-3433	7629
M10916	4037-4043	7635
M10917	4055-4061	7636
M10918	4073-4079	7637
M10919	4091-4097	7638
M10921	4127-4133	7640
M10922	4145-4151	7641
M11352	4414-4420	7644
M11353	4432-4438	7645
M11354	4450-4456	7646
M11355	4468-4474	7647
M11356	4486-4492	7648
M11421	4641-4647	7642
M11422	4659-4665	7643
M11423	4677-4683	7649
M11424	4695-4701	7650
M11471	4736-4742	7651
M11472	4754-4760	7653
M11589	4999-5005	7402
M11590	5017-5023	7403
M11591	5035-5041	7654
M11672	5089-5095	7404
M11680	5107-5113	7405
M11681	5125-5130	7406
M11689	5143-5149	7407
M11690	5161-5167	7408
M11688	5189-5195	7409
M11687	5207-5213	7410
M11691	5225-5231	7411
M11792	5309-5315	7412
M11793	5327-5333	7413
M11816	5345-5351	7414
M11918	5363-5369	7415
M12027	5450-5456	7416
M12042	5468-5475	7417
M12043	5486-5492	7418
M12044	5504-5510	7419
M12045	5537-5543	7420
M12102	5575-5581	7421
M12103	5593-5599	7422
M12104	5611-5617	7423
M12105	5629-5635	9817

FIG. I 105 MM HOWITZER, M2E1, NO. 3, FIRING SHELL, H.E., M1

INCREASE IN MUZZLE VELOCITY $(\overline{V_{n+1} - V_1})$ AND MAXIMUM PRESSURE $(\overline{P_{n+1} - P_1})$ FROM FIRST TO $(n+1)$ 'ST ROUND FOR ZONE 1 CHARGES FIRED IMMEDIATELY AFTER TWO ROUNDS AT HIGH PRESSURE FOLLOWING ZONE 7 ROUNDS

AVERAGES OVER 25 UNIFORMITY GROUPS
RADII OF CIRCLES EQUAL PROBABLE ERRORS OF POINTS

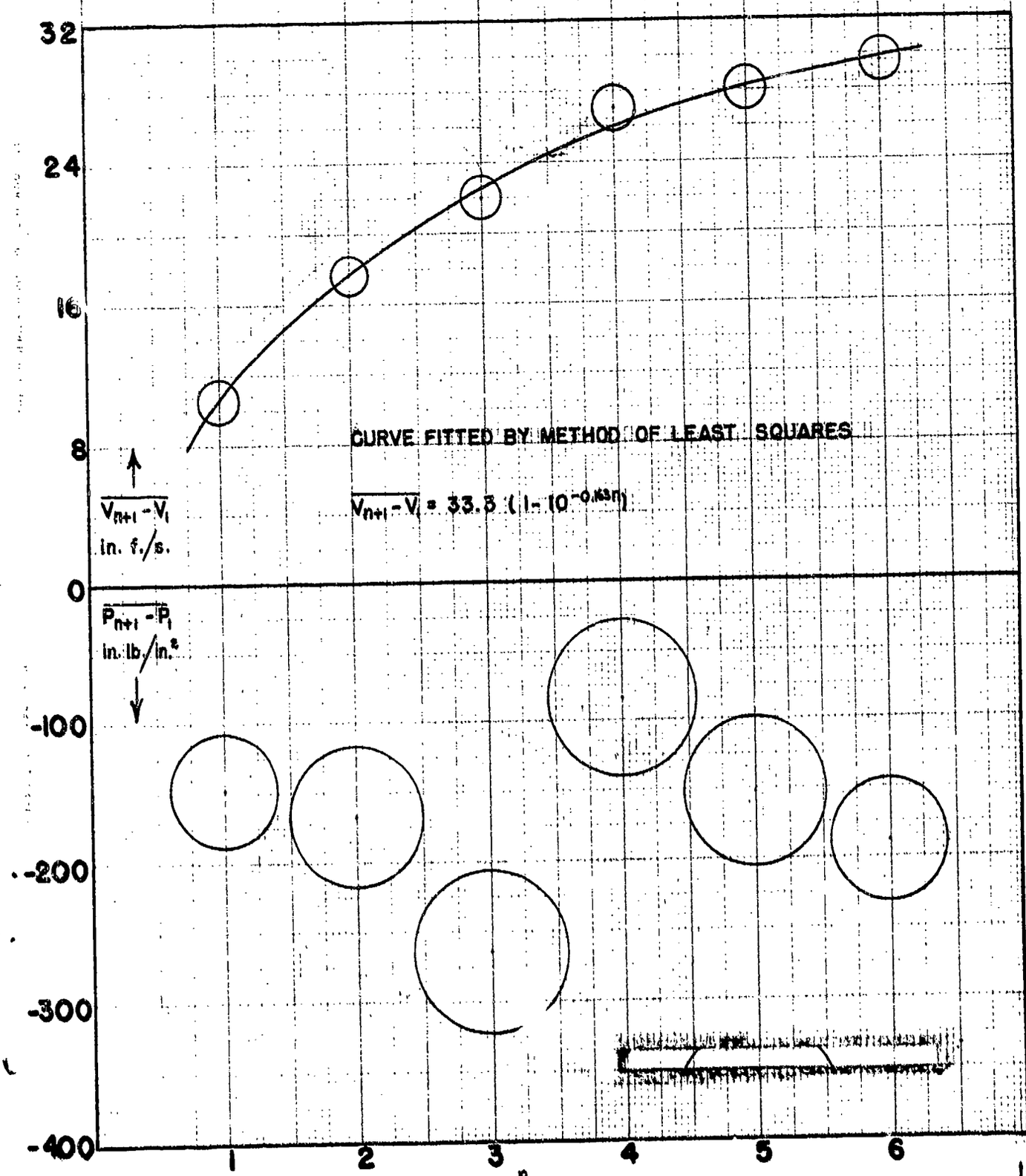

FIG. II 105 MM HOWITZER, M2E1, NO. 3, FIRING PROOF SLUG, E2

INCREASE IN MUZZLE VELOCITY $(\overline{V_{n+1}-V_1})$ AND MAXIMUM PRESSURE $(\overline{P_{n+1}-P_1})$ FROM FIRST TO $(n+1)$ 'ST ROUND FOR ZONE 1 CHARGES FIRED IMMEDIATELY AFTER TWO ROUNDS AT HIGH PRESSURE FOLLOWING ZONE 7 ROUNDS

AVERAGES OVER 15 GROUPS
RADII OF CIRCLES EQUAL PROBABLE ERROR

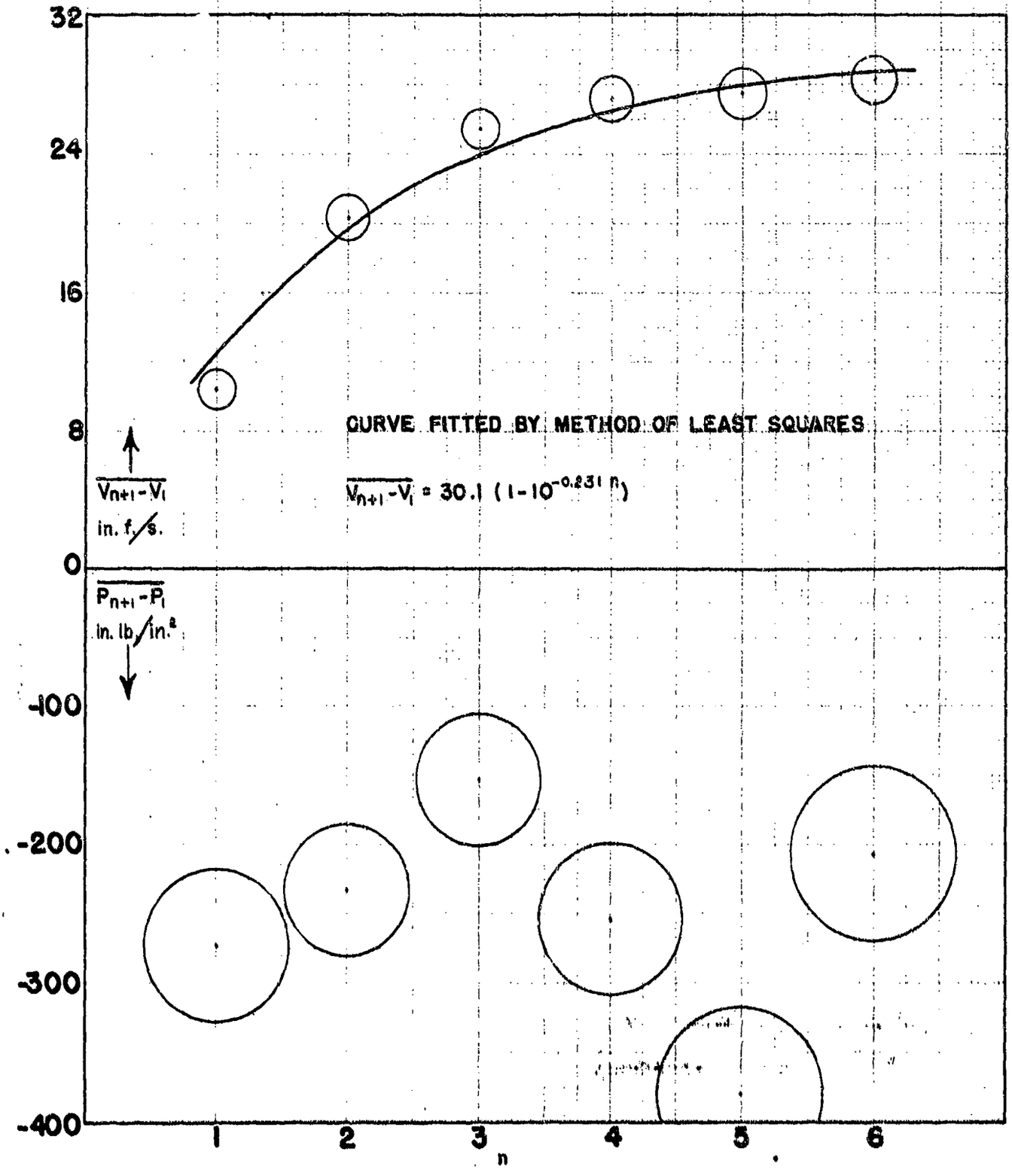

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FIG. III 105 MM HOWITZER, M2 A1, NO. 79, FIRING SHELL, H.E., M1

INCREASE IN MUZZLE VELOCITY ($\overline{V_{n+1}-V_1}$) AND MAXIMUM PRESSURE ($\overline{P_{n+1}-P_1}$) FROM FIRST TO (n+1) 'ST ROUND FOR ZONE 1 CHARGES FIRED IMMEDIATELY AFTER TWO ROUNDS AT HIGH PRESSURE FOLLOWING ZONE 7 ROUNDS

AVERAGES OVER 27 GROUPS
RADII OF CIRCLES EQUAL PROBABLE ERRORS IN POINTS

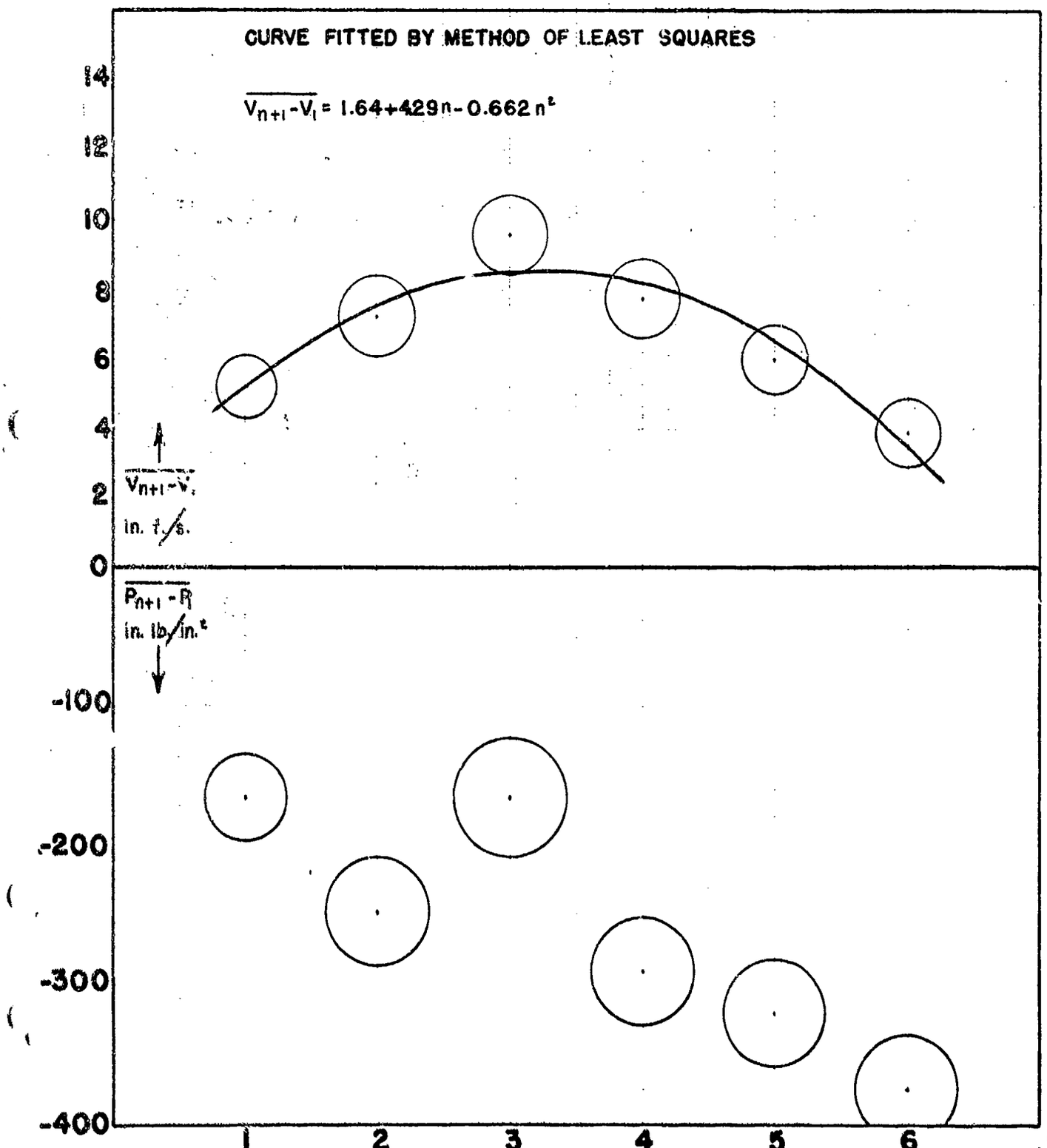

FIG. IV 105 MM HOWITZER, M2 A1, NO. 79, FIRING PROOF SLUG, E2

INCREASE IN MUZZLE VELOCITY ($\overline{V_{n+1} - V_1}$) AND MAXIMUM PRESSURE ($\overline{P_{n+1} - P_1}$) FROM FIRST TO (n+1)ST ROUND FOR ZONE 1 CHARGES FIRED IMMEDIATELY AFTER TWO ROUNDS AT HIGH PRESSURE FOLLOWING ZONE 7 ROUNDS

AVERAGE OVER 11 GROUPS
RADII OF CIRCLES EQUAL PROBABLE ERRORS OF POINTS

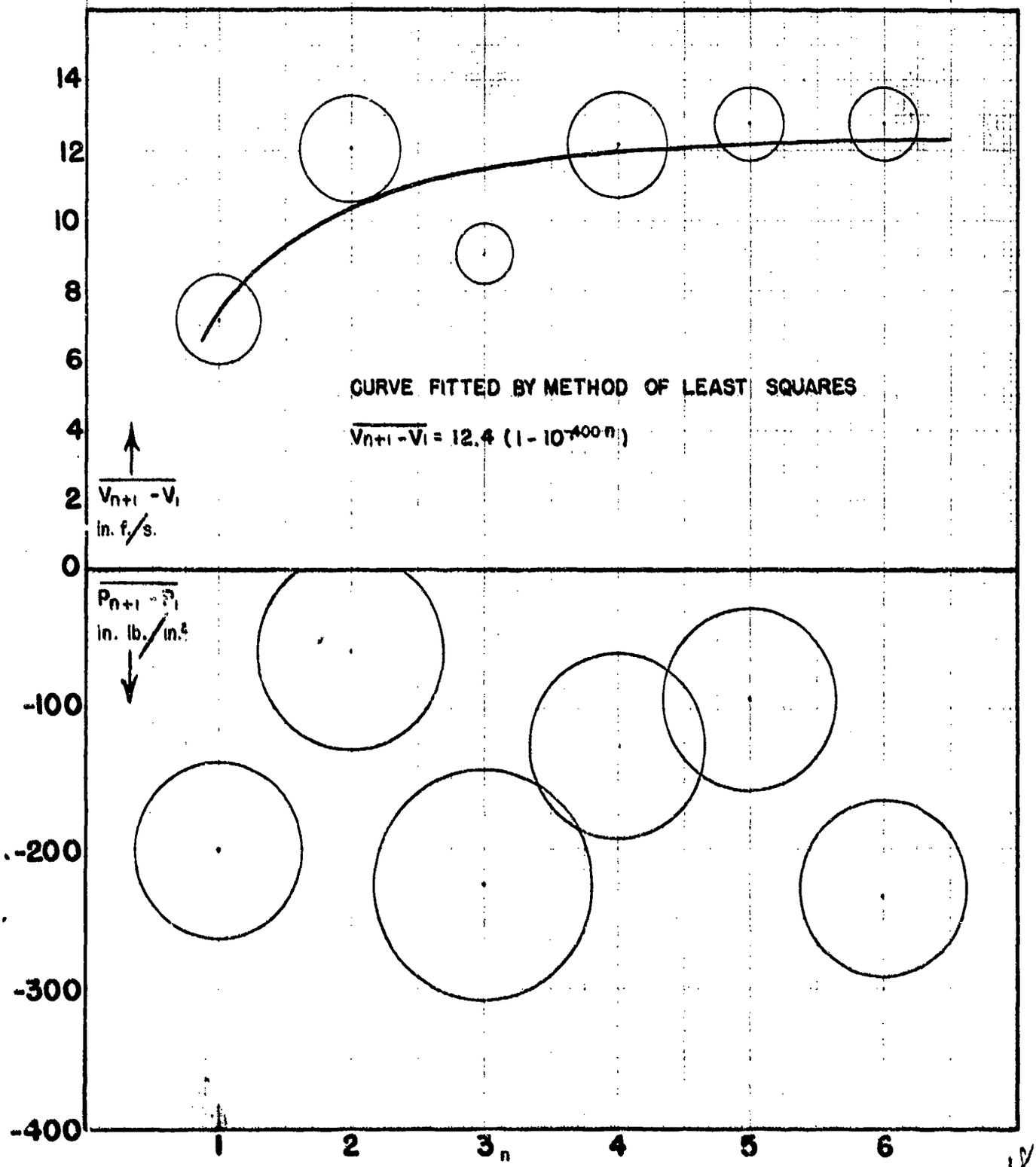

FIG. V 155 MM HOWITZER T1, NO. 2, FIRING PROOF SLUG, T11

INCREASE IN MUZZLE VELOCITY ($\overline{V_{n+1}-V_1}$) AND MAXIMUM PRESSURE ($\overline{P_{n+1}-P_1}$) FROM FIRST TO (n+1)'ST ROUND FOR ZONE I CHARGES FIRED IMMEDIATELY AFTER TWO ROUNDS AT EXCESS PRESSURE FOLLOWING ZONE 5 ROUNDS

AVERAGES OVER 88 GROUPS
RADII OF CIRCLES EQUAL PROBABLE ERRORS OF POINTS